Heat Transfer in Permalloy Films Excited by Femtosecond Optical Pulses

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Abstract: We are developing numerical models to investigate the dynamic interaction between femtosecond optical pulses and magnetic thin films. Using a FEM heat transfer model, we find two contributions to the temperature distribution: a small static component, and an intense, short-lived dynamic component.

Project in Brief

Ultrafast laser spectroscopy techniques [1] have been used to study **magnetisation dynamics** on extremely short **picosecond time scales**.

The interaction between **optical laser pulses** and a magnetic material **excites** a complex mix of **spin waves**, **surface acoustic waves**, **electric currents** and **thermal effects** [2].

In this project we are studying the interplay between these different phenomena, with the goal of creating **novel functionalities** using patterned **metamaterial structures**.

Heat Transfer Model

Following the experimental setup in [1, 2], we **simulate** the **temperature dynamics** in 20 and 50 nm thick **permalloy films**, heated by a train of 100 fs laser pulses with a 80 MHz repetition rate, average power of 2 mW and spot size of 1 µm (Fig. 1).

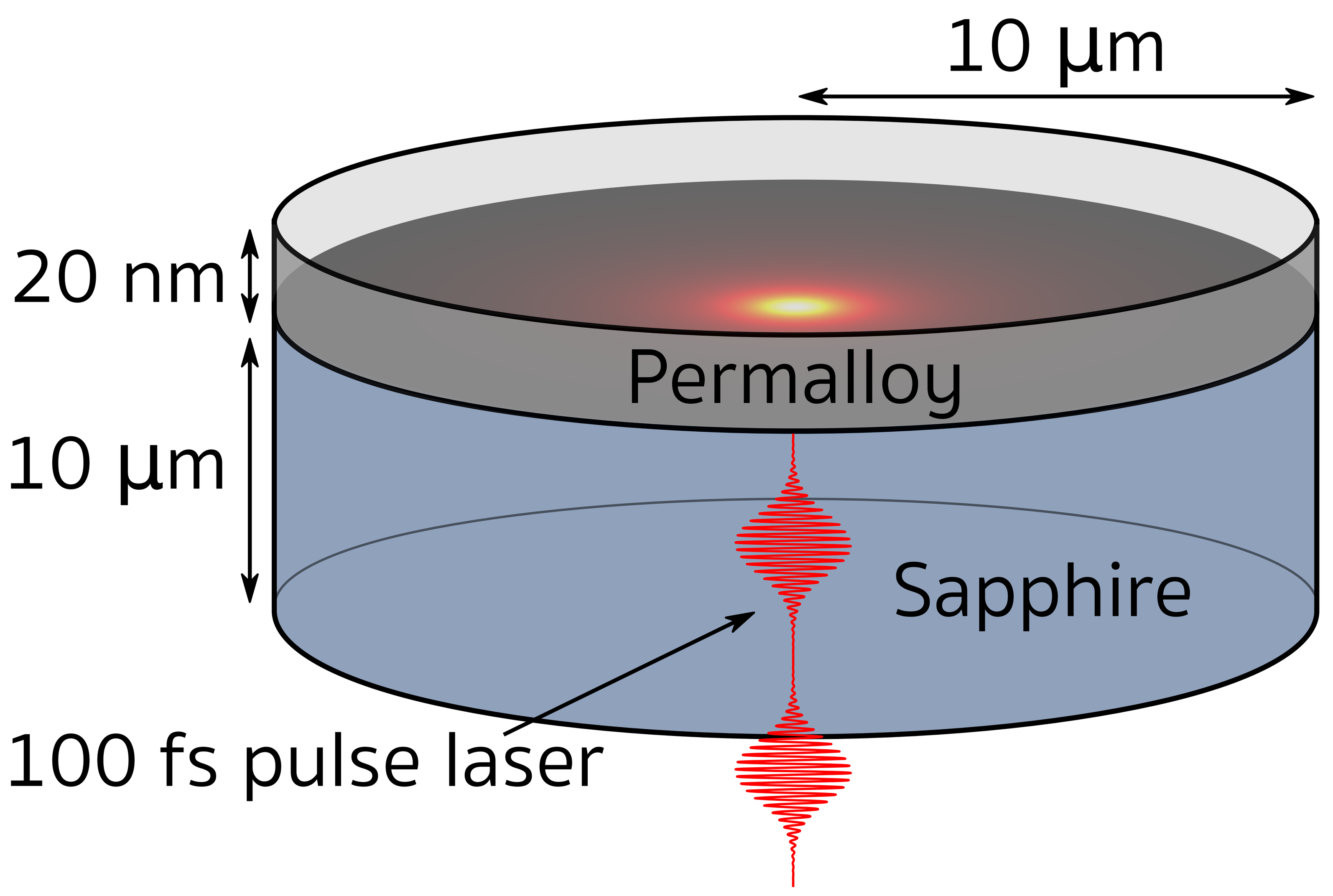


Fig. 1: Diagram of our model set up with heat simulation results superimposed

Heat Transfer Findings

We **observe** two contributions to the temperature distribution; a **static** component from **incomplete cooling** between pulses, and a **dynamic** component which dissipates before the arrival of the next pulse.

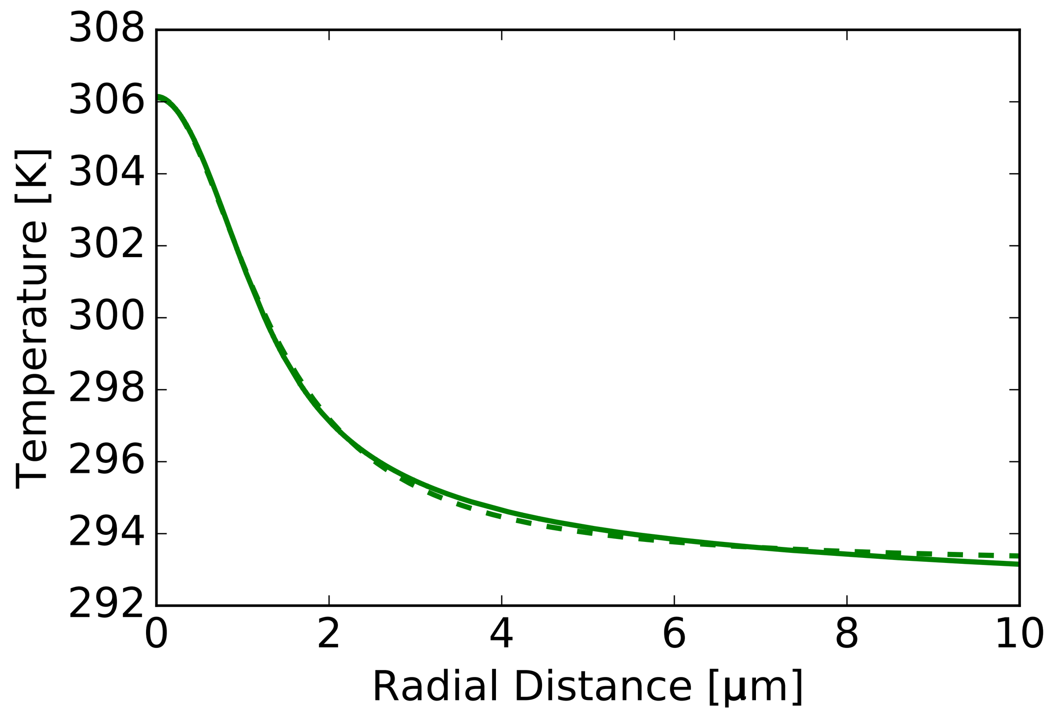
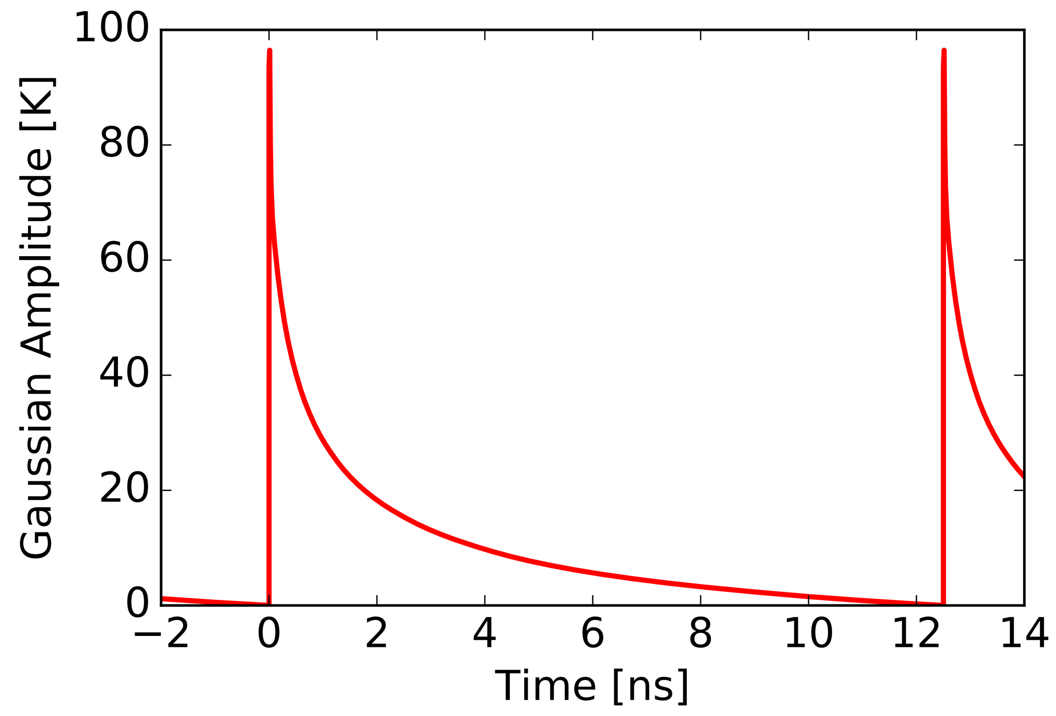


Fig. 2: Static temperature distribution across radius. r = 0 is the centre of the permalloy disc. Dashed line is a Lorentzian fit.

After 1000 pulses a stable equilibrium is reached. For experimentally large samples, a smaller peak temperature is expected.

Fig. 3: Dynamic temperature distribution across permalloy-sapphire interface. Gaussians are fitted over radius for each time and amplitude shown.

A sharp spike over the first 100 fs decays exponentially into the bulk.



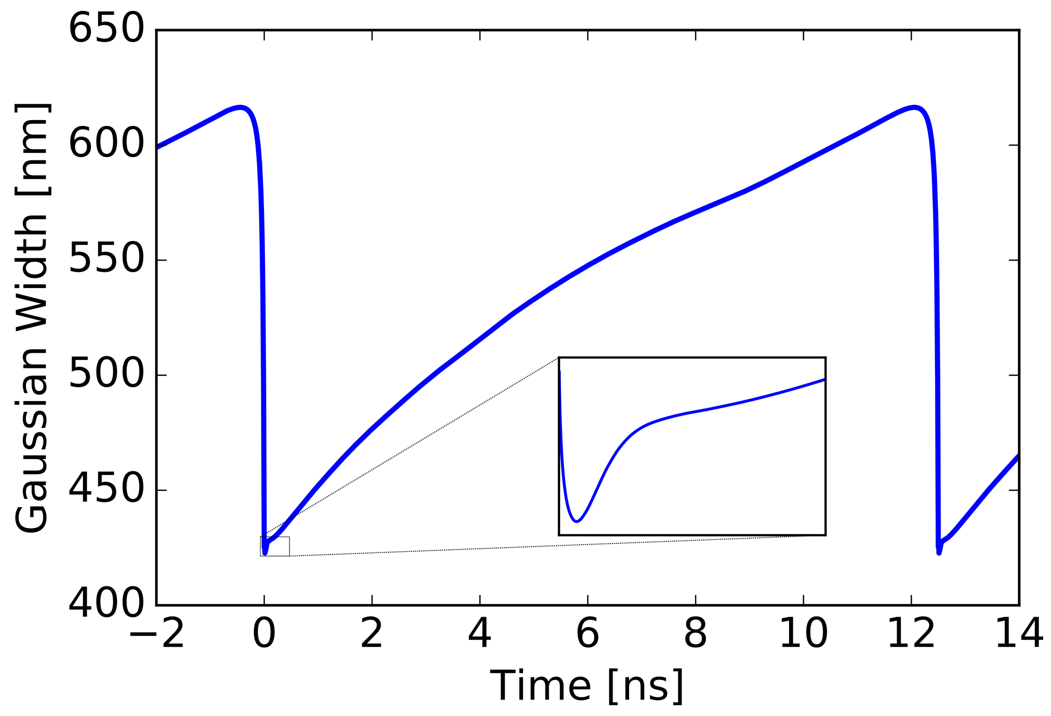


Fig. 4: Gaussian width for the fits in Fig. 3.

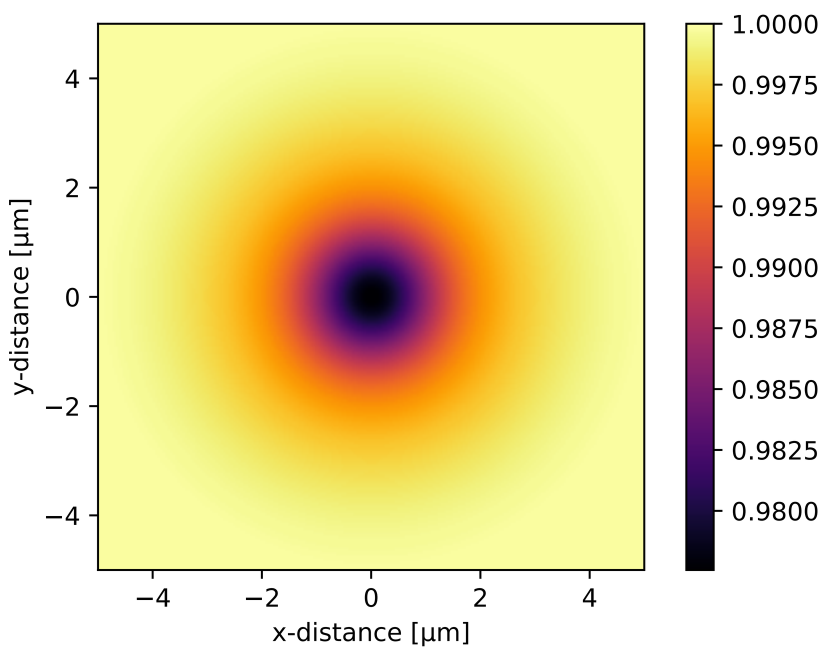
Initally, the thermal energy is focused at the laser spot. Temperature dependent thermal transport properties causes a complex dissipation effect with time.

Micromagnetic Model

For our initial analysis, we convert **temperature into saturation magnetisation**, relax to our static temperature, then instantaneously apply a time average of our dynamic temperature.

Fig. 5: Saturation magnetisation distribution for static temperature. Normalised to room temperature saturation magnetisation.

The demagnetised centre generates an effective hole, which produces a curling magnetisation distribution. This structure is intensified with dynamic heating, exciting spin waves and curving their trajectory.



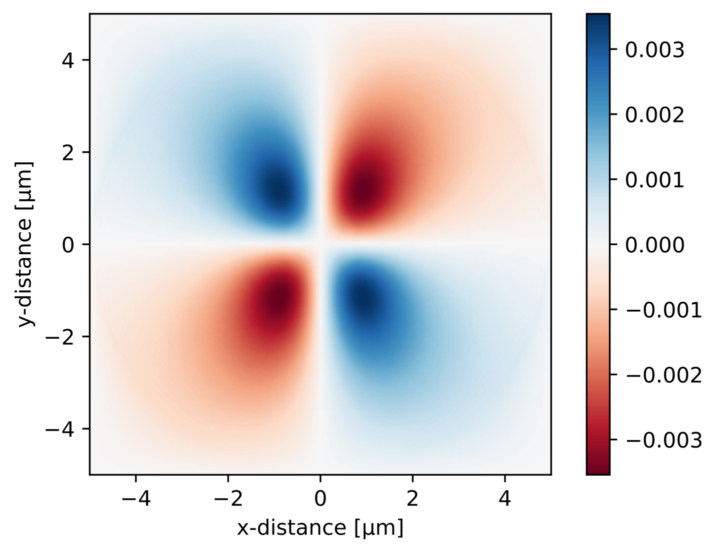


Fig. 6: Static y-component of magnetisation. Normalised to room temperature saturation magnetisation.

A quadrupole pattern emerges from curling magnetisation around the strongly demagnetised central region.

Dynamic Micromagnetic Videos

References

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